

STATE OF CALIFORNIA
AIR RESOURCES BOARD

AIR MONITORING QUALITY ASSURANCE

VOLUME II

STANDARD OPERATING PROCEDURES
FOR
AIR QUALITY MONITORING

APPENDIX D
THERMO ELECTRON MODEL 14B NO-NO₂-NO_x ANALYZER

MONITORING AND LABORATORY DIVISION

APRIL 1985

TABLE OF CONTENTS

APPENDIX D

THERMO ELECTRON MODEL 14B NO-NO₂-NO_x ANALYZER

TABLE OF CONTENTS

D.1 - STATION OPERATOR'S PROCEDURES	<u>PAGES</u>	<u>REVISION</u>	<u>DATE</u>
D.1.0 GENERAL INFORMATION	3	2	3-01-85
D.1.0.1 Theory			
D.1.0.2 Analytical Cycle			
D.1.0.3 Cautions			
D.1.1 INSTALLATION PROCEDURE	2	1	4-01-85
D.1.1.1 Physical Inspections			
D.1.1.2 Initial Start Up			
D.1.1.3 Analyzer Alignment			
D.1.1.4 Calibration			
D.1.2 ROUTINE SERVICE CHECKS	5	1	1-01-85
D.1.2.1 General Information			
D.1.2.2 Daily Checks			
D.1.2.3 Weekly Checks			
D.1.2.4 Monthly Checks			
D.1.2.5 Semi-Annual Checks			
D.1.3 DETAILED MAINTENANCE AND ALIGNMENT PROCEDURES	5	1	2-01-84
D.2 - ACCEPTANCE TEST PROCEDURE			
D.2.0 PROCEDURE	5	0	7-01-80
D.2.0.1 General Information			
D.2.0.2 Physical Inspections			
D.2.0.3 Operational Tests			

TABLE OF CONTENTS (cont.)

APPENDIX D

THERMO ELECTRON MODEL 14B NO-NO₂-NO_x ANALYZER

TABLE OF CONTENTS

D.3 - CALIBRATION PROCEDURE		<u>PAGES</u>	<u>REVISION</u>	<u>DATE</u>
D.3.0	CALIBRATION PROCEDURE OVERVIEWS	5	3	4-01-85
D.3.0.1	Introduction			
D.3.0.2	Basic Apparatus			
D.3.0.3	Dynamic Parameter Specification			
D.3.0.4	References			
D.3.1	GAS PHASE TITRATION CALIBRATION	8	2	2-01-84
D.3.1.1	Principle			
D.3.1.2	Apparatus			
D.3.1.3	As Is Calibration			
D.3.1.4	Final Calibration			

APPENDIX D

THERMO ELECTRON MODEL 14B NO-NO₂-NO_x ANALYZER

FIGURES

	<u>Page</u>
Figure D.1.0.1..Model 14B/ NO-NO ₂ -NO _x Analyzer Gas Flow/Electronics Diagram	3
Figure D.1.2.1...Monthly Control Maintenance Checksheet	5
Figure D.1.3.1...TECO 14B/E Electronic Assembly-Component Locations	5
Figure D.2.0.1...Acceptance Test Mini Report	5
Figure D.3.0.1....Diagram of Typical GPT Calibration System	5
Figure D.3.1.1...NO-NO ₂ -NO _x Chemiluminescent Analyzer Calibration Datasheet	7

TABLES

Table D.1.2.1...Thermo Electron Model 14B NO-NO ₂ -NO _x Analyzer Service Schedule.	4
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STATE OF CALIFORNIA
AIR RESOURCES BOARD

AIR MONITORING QUALITY ASSURANCE

VOLUME II

STANDARD OPERATING PROCEDURES

FOR

AIR QUALITY MONITORING

APPENDIX D.1

STATION OPERATOR'S PROCEDURES

FOR THE

THERMO ELECTRON MODEL 14B NO-NO₂-NO_x ANALYZER

MONITORING AND LABORATORY DIVISION

APRIL 1985

D.1.0 GENERAL INFORMATION

D.1.0.1 THEORY - The Thermo Electron NO-NO₂-NO_x analyzer measures the chemiluminescence produced by the reaction of ozone with the NO contained in a sample of ambient air. The chemiluminescence measurement is proportional to the NO concentration. A detailed discussion of the scientific basis of the analyzer measurement principle is contained in the Manufacturer's Instruction Manual.

This Appendix supplements the Manufacturer's Instruction Manual with instructions for installing and servicing the analyzer. Separate appendices are available for acceptance testing and calibrating the analyzer.

D.1.0.2 ANALYTICAL CYCLE - The following procedure describes the gas flow and analysis of an air sample entering the sample port (see Figure D.1.0.1). The sample input has two flow modes. The first mode (NO mode) is a direct path of sample to the reaction chamber. In the second mode (NO_x mode), the sample is passed through a NO₂ to NO converter where all NO₂ is converted to NO, then it passes to the reaction chamber. Within the reaction chamber, the NO in the sample reacts with ozone to produce NO₂ and the characteristic chemiluminescence. Ozone required for the reaction is produced within the analyzer by passing dry filtered air through a high voltage AC field (silent discharge generator).

The light signal from the chemiluminescent reaction passes through an optical filter to a high sensitivity photomultiplier tube (PMT). The optical filter blocks out light of wavelength less than 6000 Å, thus eliminating possible interferences due to other chemiluminescent reactions. The electrical signal from the photomultiplier is then fed to the amplifier. The amplifier converts the current signal from the photomultiplier into a voltage signal, and it amplifies the signal level to a maximum of 10 volts output. Every 30 seconds, a solenoid valve switches from the NO mode to the NO_x mode. The difference between the NO and NO_x modes is the amount of NO₂ in the sample. For calibration, the high voltage to the PMT or the gain on the amplifier is adjusted to agree with known NO or NO₂ concentrations. DC dark current of the PMT is suppressed by adjusting the background suppression pot. Finally, reaction gases from the reaction chamber are drawn out of the chamber by a vacuum pump. The unreacted ozone is scrubbed from the exhaust gas by activated charcoal.

D.1.0.3 CAUTIONS

1. The exhaust from the MB-155 vacuum pump contains harmful amounts of ozone. Vent this exhaust to the outside.
2. The analyzer contains a 7000 VAC and a -1900 VDC power supply. When working on this analyzer, use all high voltage precautions.
3. When cleaning the photomultiplier tube, or its cavity, be sure to keep the photomultiplier tube in subdued light at all times. Exposure to high light levels can result in permanent damage to the tube.
4. AC power for the analyzer must have a third wire for ground.

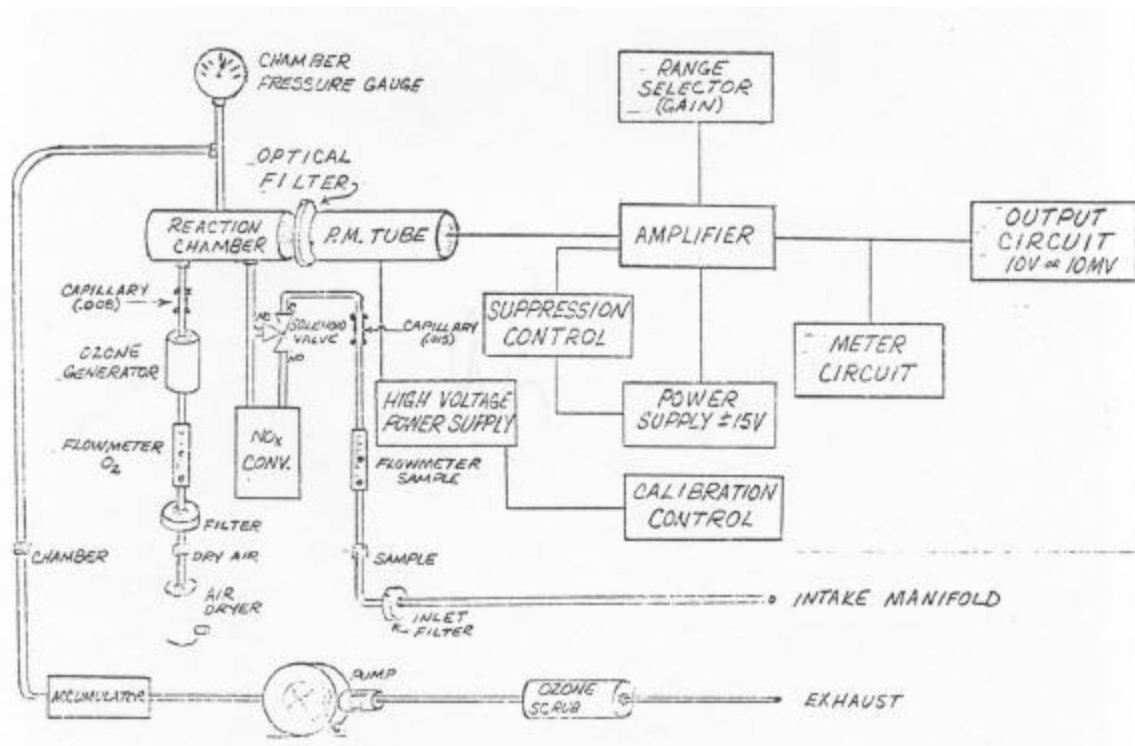


Figure D.1.0.1
Model 14B/E NO-NO₂-NO_x Analyzer Gas Flow/Electronics Diagram

D.1.1 INSTALLATION PROCEDURE

D.1.1.1 PHYSICAL INSPECTIONS - Release the drawer locks and inspect the inside of both compartments for physical damage: cracks, broken lines, and loose PC boards. The sequence/memory PC board must be properly aligned with its 22-pin connector and the board pushed all the way into the connector. Verify that the cables are connected properly, the sample and ozone particulate filters are in place, the lines are connected at the rear bulkhead, the ozone scrubber is in place, the reaction chamber pump is mounted properly on the shock tray, and the 3-wire cord is connected. Repair any irregularities prior to proceeding.

NOTE: Whenever removing or installing the PC boards, make sure the main power switch is in the "OFF" position.

D.1.1.2 INITIAL START UP - For a thorough discussion of the initial start up procedure, refer to Section II - Installation, and Section III - Assembly, in the Thermo Electron Model 14B/E Chemiluminescent NO-NO₂- NO_x Analyzer Instruction Manual.

1. Push the "POWER ON" switch. The cooling fan, converter, thermoelectric cooler and instrument electronics should now be powered. Also, plug in the pump. It will start pumping upon application of power.
2. The reaction chamber gauge should indicate -21 ± 2 inches of Hg. (At higher altitudes, this vacuum may be less.) There is no adjustment for the reaction chamber vacuum.
3. Verify that the NO₂ to NO converter temperature is within the range listed below. Note that Monitor Labs converters are preset at the factory (units contain a bi-metallic switch). The Instrumentation Lab further readjusts these units, as necessary to meet the minimum converter efficiency of 97%. Prior to the following checks, allow 30 minutes for converter warm up.
 - a. Monitor Labs converter: 315°C to 350°C. Do not make any adjustments in the field.
 - b. Thermo Electron converter: 400°C to 450°C. Readjust temperature controller as necessary.
4. Turn the meter switch to "NO MANUAL" and the range selector switch to the "ZERO" position. Check the panel meter for a zero indication. Refer to Section D.1.3 if readjustment is necessary.

With the meter switch still on "NO MANUAL", turn the range switch to full scale. The meter should indicate full scale. If readjustment is necessary, refer to Section D.1.3.

5. Turn the meter switch to any automatic position. The instrument will automatically cycle between the NO and NO_x modes about every 30 seconds. With the range switch still in full scale, the NO and the NO_x reading should attain full scale values within approximately 5-10 minutes. The corresponding NO₂ value should be zero. Refer to Section D.1.3 if readjustment is necessary.
6. After the instrument has been operating for approximately 1 to 2 hours, turn the meter switch again to "NO MANUAL" and the range switch to the .050 ppm range. Turn the background suppression potentiometer to the extreme counterclockwise position. The instrument reading is the unsuppressed photomultiplier dark current; a value of less than .015 ppm (15 ppb) is typical. If the dark current is significantly higher, allow additional time for the photomultiplier to cool.
7. After the instrument has been operating for approximately 1 to 2 hours, turn the range selector switch to the appropriate range (usually 1 ppm). Connect the sample to be measured to the "SAMPLE IN" port at the rear of the instrument. Push the "OZONE" switch to energize the ozone generator. By turning the meter switch to the appropriate position, the analyzer's meter will display the NO, NO₂ and NO_x concentrations being monitored.

D.1.1.3 ANALYZER ALIGNMENT - See Section D.1.3.1.

D.1.1.4 CALIBRATION - See Appendix D.3 for detailed calibration procedures.

D.1.2 ROUTINE SERVICE CHECKS

D.1.2.1 GENERAL INFORMATION - Perform routine maintenance in accordance with the schedule noted in Table D.1.2.1 and the procedures documented in Sections D.1.2 and D.1.3 of this Volume. Perform non-routine maintenance as required to assure accurate and complete data recovery. Notations of all maintenance and weekly checks are made on the strip charts and on the Monthly Quality Control Maintenance Checksheet, hereafter referred to as the Checksheet (Figure D.1.2.1). At the end of the each month, forward the original copy of the Checksheet to your supervisor for review. The duplicate copy remains in the maintenance log with the analyzer.

D.1.2.2 DAILY CHECKS - Make the following checks each day you service the monitoring site to assure proper analyzer performance between weekly maintenance periods.

NOTE: To facilitate your visual checks of flow meters, temperature indicators and gauges you may choose to print the correct readings at the time of the most recent calibration on Dymo tape and attach the tapes to the analyzer in close proximity to the indicating device.

1. Sample and Ozone Flow Meters - Verify that both flow meters indicate the flow rates recorded at the completion of the last calibration.
2. Reaction Chamber Vacuum - Reaction chamber vacuum is critical and must remain within ± 1 " Hg of the value at the time of calibration. Verify that the reaction chamber vacuum has not changed since the last calibration. If the vacuum has decreased (i.e. a lower reading on the vacuum gauge) the system may have a leak, dirty capillary, or faulty pump. Correct the problem if possible. If corrective actions fail to reestablish the reaction chamber vacuum to within ± 1 " Hg of the vacuum at the time of the last calibration, immediately contact your supervisor.
3. NO₂ to NO Converter Temperature - Verify that the indicated temperature of the NO₂ to NO converter is within $\pm 10^{\circ}\text{C}$ ($\pm 18^{\circ}\text{F}$) of the set temperature at the time of the latest calibration (ref: ADD-47) and within the temperature range specified in Section D.1.1.2.
4. Silica Gel - Verify that the Silica Gel drier on the inlet of the ozone generator has unspent desiccant. The desiccant will turn from a dark blue (dry) to pink (moist) color as it becomes spent. Desiccant must be changed before all the blue color is gone. Refill the cannister with dried desiccant. Recharge the spent desiccant by heating it to drive off the moisture.

5. Strip Charts - You must become familiar with the daily pattern of pollutant concentrations at each site. Check the strip charts for abnormal traces. Flat traces showing no activity for full 24 hour periods, traces showing excessive noise (scatter), NO or NO₂ values greater than NO_x values, and unusual peaks should be noted on the chart and on the Checksheet. Whenever possible, isolate the cause for these abnormal chart traces.
6. Solenoid Timing - Verify that the NO_x/NO mode solenoid is functioning. The solenoid's switching should produce an audible click and the mode lights on the analyzer's front panel should alternate between NO_x and NO modes. Typically, the solenoid must switch between modes at least every 30 seconds.

D.1.2.3 WEEKLY CHECKS - Perform the following checks each week. Record the as found and final readings on Checksheet and make appropriate notations on the strip charts.

1. Electronic Zero and Span - Following the procedures in Section D.1.3.1, check the electronic zero and span. Reset the analyzer if the test results differ by more than $\pm 0.5\%$ of full scale at either zero or span.
2. Sample Particulate Filter - At least weekly, replace the in-line Teflon sample particulate filter. Note the filter cleanliness and, if necessary, increase the replacement frequency. Change the filter if even a slight particulate coating or discoloration is visible. Note any unusual discolorations on the Checksheet.
3. Sample Capillary - Remove and inspect the glass sample flow capillary and "O"-ring, and replace the "O"-ring if it is cracked and/or deteriorated. Push a thin wire through the capillary to clear it of particulates, if necessary, then rinse the capillary with alcohol and blow it dry. After cleaning and inspection, reassemble the capillary and "O"-ring and reinstall the capillary in the analyzer, noting maintenance performed on the Checksheet and strip chart.
4. Dynamic Span Check - Perform an analyzer span check using the procedures in Section D.1.3.3. At those sites without automatically daily calibration systems, record the NO span reading in the space provided on the Checksheet. At those sites with automatic calibrators, the NO value is not to be recorded on the analyzer's Checksheet since it appears on the calibrator Checksheet. When the daily or weekly span check indicates the analyzer's response is greater than $\pm 10\%$ from true, conduct a full maintenance check of the analyzer. If you cannot correct the problem, contact your supervisor to arrange for a recalibration.

D.1.2.4

MONTHLY CHECKS

1. Ozone Capillary - Remove the glass ozone flow capillary and "O"- ring. Inspect and clean the capillary using the procedure in D.1.2.3.3. Record the date cleaned on the Checksheet and not maintenance performed on the strip chart.
2. Ozone Particulate Filter - Replace the ozone particulate filter. Record the date of replacement on the Checksheet and note maintenance performed on the strip chart.
3. "Calibrate" and "Background Suppression" switches - Release the electronics assembly (top assembly) from its locked position on its rack slides by depressing the buttons on the assembly handle, slide the assembly forward and note the positions of the calibrate (L, M, H) and the suppression switches (L or H). Record the switch positions on the Checksheet.
4. Background Suppression - Following Section D.1.3.2 procedures, check the Photomultiplier Tube (PMT) dark current. If erratic, or unusually high dark current is found, refer to Section VI - Troubleshooting, in Thermo Electron's Model 14B/E Instruction Manual. On the Checksheet, record the unsuppressed dark current, in ppb, as read from the strip chart, and the background suppression potentiometer setting (front of electronics assembly) with the dark current fully suppressed.
5. Cycle Time - Time the period from the start of the NO cycle to the start of the NO_x cycle (NO cycle); then time the start of the NO_x cycle to the start of the NO cycle (NO_x cycle). Each cycle should be less than 30 seconds. Record the NO and NO_x cycle times on the Checksheet.

D.1.2.5

SEMI-ANNUAL CHECKS

1. Multipoint Calibration - Monthly, record the date of the last multipoint calibration on the Checksheet. One month prior to the semi-annual calibration, contact your supervisor to schedule the calibration.

The calibration procedure is contained in Section D.3.1.

TABLE D.1.2.1

Thermo Electron Model 14B NO-NO₂-NO_x Analyzer Service Schedule

	Daily*	Weekly	Monthly	Semi-Annual
Sample Flow	X			
Ozone Flow	X			
Reaction Chamber Vacuum	X			
Converter Temperature	X			
Chart Trace	X			
Solenoid Function Check	X			
Silica Gel	X			
Electronic Zero & Span		X		
Dynamic Span		X		
Sample Particulate Filter Replacement		X		
Clean Sample Flow Capillary		X		
O.C. Checksheets		X	X	
Background Suppression			X	
Cycle Time			X	
Ozone Filter Replacement			X	
Clean Ozone Flow Capillary			X	
Clean Ozone Flow Capillary				X
Clean Rotameters	As Required			

*Or each day the operator services the analyzer

CALIFORNIA AIR RESOURCES BOARD
MONTHLY QUALITY CONTROL MAINTENANCE CHECKSHEET
THERMO ELECTRON MODEL 14B NO-NO₂-NO_x ANALYZER

Location: Stockton Month/Year: January 1981
Station Number: 39-252 Technician: Jackson
Analyzer Property Number: 3930 Agency: ARB

Date	Electronic Check							Flow Reading		Dynamic Spas Check*	Calib. Pot Setting	Converter Temp	Chamber Vacuum
	Chart Reading: As Found/Final							Sample	O ₂				
	Zero			Span						Read ppm			
	NO	NO ₂	NO _x	NO	NO ₂ Oper	NO ₂ Test	NO _x					NO	
												"	"Hg
5	.001/	.001/	.001/	1.001/	.001/	1.001/	1.00/	3.0	4.2	.625	765	438	22.5
12	.001/	.002/	.002/	1.002/	.001/	1.002/	1.002/	3.0	4.2	.617	765	436	22.5
19	.001/	0	0	1.001/	.001/	1.002/	1.002/	2.9	4.3	.609	765	437	22.5
26	.002/.001	.001/0	0/0	1.001/1.00	.001/.001	1.002/1.001	1.003/1.001	2.9	4.6	.615	765	437	22.6
	/	/	/	/	/	/	/						
	/	/	/	/	/	/	/						

Span cylinder number CC 12781; Concentration .610 NO ppm (only required if daily gas calibration system is not in use).

Operator instructions:

- 1) **Daily Checks:** Sample and ozone flow readings, chamber vacuum, converter temperature (record weekly); Check chart traces, analyzer range, and solenoid cycling; Check silica gel.
- 2) **Weekly Checks:** Electronic zero and span; Dynamic span; Calibration settings; Replace sample particulate filter; Clean sample flow capillary, dates cleaned 1-5, 1-12, 1-19, 1-26.
- 3) **Monthly Checks:** Clean ozone flow capillary, date cleaned 1-5-81; Replace ozone particulate filter, date replaced 1-28-81; Calibration switch (LMH) M; Suppression switch (LH) L; Cycle time (sec): NO 41.7 NO₂ 42; Background suppression pot setting: As found 062 Final 060, unsp. Dark current 2.4 ppb, date checked 1-19-81.
- 4) **Semi-Annual Checks:** Multipoint calibration, date last calibrated 10-7-80;

Date	Comments or Maintenance Performed
5	Changed silica gel & sample particulate filter
12	" " " " " " "
19	" " " " " " "
26	" " " " " " "

Reviewed By: LSR

Date: 2/11/81

Figure D.1.2.1
Monthly Quality Control Maintenance Checksheet

D.1.3 DETAILED MAINTENANCE AND ALIGNMENT PROCEDURES

In the following procedures, always allow the analyzer time to develop a stable recorder trace of at least five minutes duration after any adjustments are made. Also, whenever maintenance requires that the AC power be removed from the analyzer, sufficient time should be given to assure PMT cooling before ambient monitoring is reinitiated. Monitoring may commence when the analyzer's unsuppressed PMT dark current reaches its pre-maintenance level.

D.1.3.1 ALIGNMENT PROCEDURES (includes electronic zero and span) - See Figure D.1.3.1 for component locations.

1. Set the range selector switch in the "ZERO" position, the mode switch in NO manual and the ozone switch in the off position. If the recorder trace deviates from zero by more than $\pm 0.5\%$ of full scale, reset the analyzer's electronic zero using the following procedures:
 - a. Release the electronics assembly (top drawer) from its locked position on its rack slides by depressing the buttons on the assembly handles and sliding it out. Using a digital voltmeter (10 VDC range), monitor the output of the 310J amplifier at the test points on the amplifier housing.
 - b. Adjust the amplifier zero potentiometer located on the front panel of the analyzer's electronics assembly for $0.000 \pm .001$ VDC on the digital voltmeter.
 - c. Jumper the analyzer's meter terminals (inside top drawer) with a wire or screw driver and zero the front panel meter using the mechanical adjust screw on the face of the meter. Remove the short.
2. Place the integrator toggle switch on the integrator printed circuit board in the forward position, disabling the integrator.
3. If any of the zero traces for NO or NO_x differ from chart zero by more than $\pm 0.5\%$ of full scale, then adjust the appropriate zero pot on the integrator printed circuit board. Do not adjust the NO₂ zero pot (Z2) at this time.

RECORDER ZERO TRACE

ZERO POT

NO	Z1
NO ₂	Z2
NO _x	Z3

4. Set the range selector switch to "FULL SCALE" position. Allow the analyzer time to develop a stable trace. If the recorder trace for NO or NO_x deviates from full scale (typically 100 chart divisions) by more than $\pm 0.5\%$, reset the electronic span using the following procedure:
 - a. Using a digital voltmeter, monitor the output of the 310J amplifier at the test points on the amplifier housing.
 - b. Adjust the trimpot on the amplifier housing for a $+10.00 \pm 0.1$ VDC indication on the digital voltmeter.
 - c. Adjust the amplifier calibrate potentiometer (marked "METER CAL") located inside the electronics assembly for a full scale indication on the front panel meter.

CAUTION: Do not adjust the front panel span pot.

 - d. Attach the leads of the digital voltmeter to pins 1 and G (input side) on the integrator printed circuit board located at the rear left hand corner of the electronics assembly. Adjust potentiometer P1 on the sequence/memory printed circuit board for a $+10.00 \pm .01$ VDC reading on the voltmeter.
 - e. Repeat Step d. with the voltmeter leads attached to pins 3 and G (input side) on the integrator printed circuit board. Adjust potentiometer P3 on the sequence/memory printed circuit board to obtain a $+10.00 \pm .01$ VDC reading on the voltmeter.
 - f. Set the digital voltmeter on the 1 VDC or lowest range. Attach the leads of the digital voltmeter to pins 1 and G (output side) on the integrator printed circuit board. Adjust potentiometer FS 1 on this board for a $+1.000 \pm .001$ VDC reading on the voltmeter and a full scale recorder trace $\pm 0.5\%$.
 - g. Repeat step f. with the voltmeter leads attached to pins 3 and G (output side) on the integrator printed circuit board. Adjust potentiometer FS 3 on this board for a $+1.000 \pm .001$ VDC reading on the voltmeter.
 - h. Attach the digital voltmeter leads to pins 2 and G (input side) on the integrator printed circuit board. Adjust potentiometer P4 on the sequence/memory printed circuit board for 0.00 VDC on the voltmeter, or minimum reading if greater than zero.

- i. Attach the digital voltmeter leads to pins 2 and G (output side) on the integrator printed circuit board and adjust zero port Z2 to 0.000 VDC on the voltmeter or zero on the recorder.
- j. Set the digital voltmeter on the 10 VDC range. With the digital voltmeter leads attached to pins 2 and G (input side) on the integrator printed circuit board, move the sequence/memory printed circuit board toggle switch SW 1 to the left (test position). Adjust P2 on this board for $+10.00 \pm .01$ VDC on the voltmeter.
- k. Reset the digital voltmeter to the 1 VDC or lowest range. Repeat step f. with the voltmeter leads attached to pins 2 and G (output side) on the integrator printed circuit board. Adjust the potentiometer FS 2 on this board for a $+1.000 \pm .001$ VDC reading on the voltmeter and a full scale recorder trace $\pm 0.5\%$.

RECORDER SPAN TRACE

SPAN POT

NO

FS 1

NO₂

FS 2

NO_x

FS 3

When all traces are within $\pm 0.5\%$ of full scale, the analyzer is zeroed and spanned.

5. Return the analyzer controls and toggle switches to their operating positions.

D.1.3.2 BACKGROUND SUPPRESSION

1. Turn off the O₃ generator and place the range selector switch (front panel) on the .05 ppm range.
2. Record the as found background suppression potentiometer (front panel) setting on the Checksheet.
3. Turn the background suppression potentiometer completely counterclockwise. Read the front panel meter and record the unsuppressed background current (in ppb) on the Checksheet.
4. Turn the background suppression potentiometer clockwise until the background current indicates zero ppb on the front panel meter. Record the final background suppression potentiometer dial setting on the Checksheet.

5. Return analyzer controls to their normal operating positions.

D.1.3.3 DYNAMIC SPAN CHECK - The dynamic span checks are performed at fully equipped stations by an automatic calibration system.

1. Stations with Automatic Calibration Systems - Check the analyzer span as follows:
 - a. Refer to the Dasibi Gas Calibration System Monthly Quality Control Maintenance Checksheet. Find the most recent NO value from step 2 of the timer program; verify the value is consistent with previous daily readings. Call this value "y".
 - b. Determine the predicted NO concentration by referring to the most recent Dasibi Gas Calibration System Monthly Statistical Analysis. Find the predicted NO value under "true ppm" for the first point of the auto program. Call this value "x".
 - c. Calculate the percent difference from true value:

$$\text{Percent Difference} = \frac{y - x}{x} \times 100$$

If the percent difference is more than $\pm 10\%$, and trouble-shooting the analyzer fails to show any problem, contact your supervisor to arrange for a recalibration.

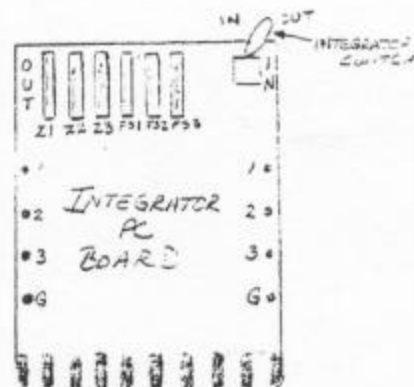
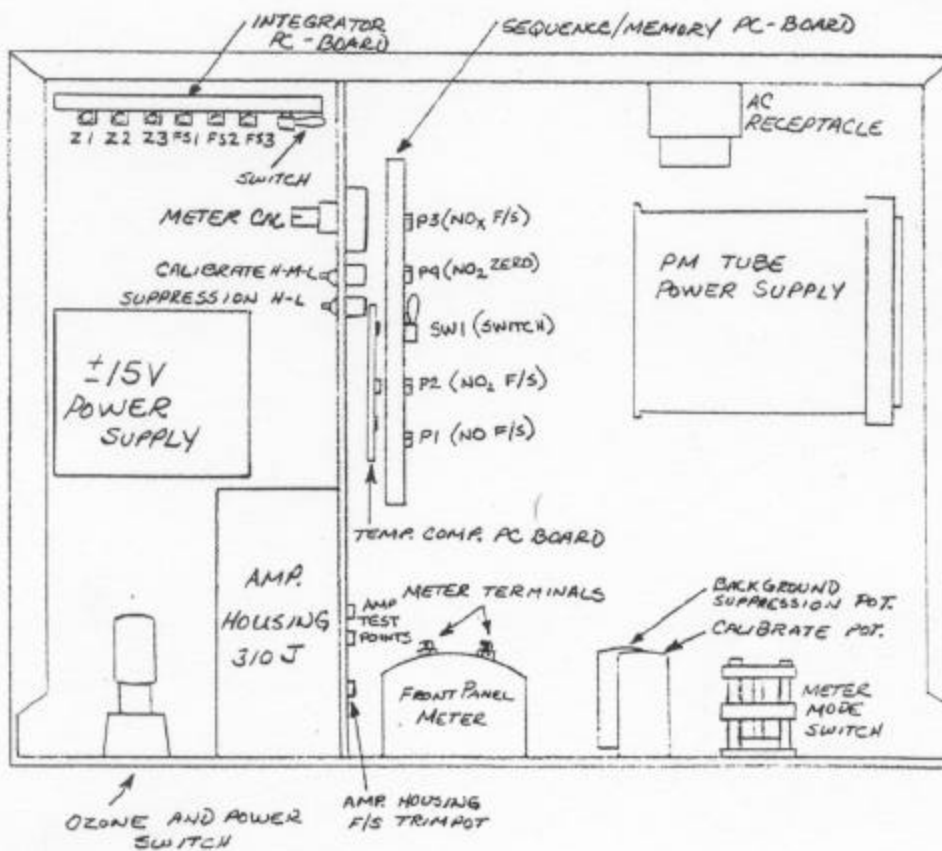


Figure D.1.3.1
Teco 14B/E Electronic Assembly - Component Locations

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VOLUME II

STANDARD OPERATING PROCEDURES

FOR

AIR QUALITY MONITORING

APPENDIX D.2

ACCEPTANCE TEST PROCEDURE

FOR

CHEMILUMINESCENT NO-NO₂-NO_x ANALYZERS

MONITORING AND LABORATORY DIVISION

JULY 1980

D.2.0 PROCEDURE

D.2.0.1 GENERAL INFORMATION - Before beginning acceptance testing of the analyzer, read the Manufacturer's Instruction Manual and become familiar with the analyzer before attempting its operation. Start an analyzer acceptance test mini report (see Figure D.2.0.1), an acceptance test progress report, and a recorder chart trace. Note the settings of all duo dials on the chart.

D.2.0.2 PHYSICAL INSPECTIONS - Unpack the analyzer from its shipping carton and check for shipping damage before proceeding with the test. Report any damage observed.

1. Check the analyzer for compliance to the physical specifications listed as part of the purchase order and insure that the analyzer is complete as ordered (i.e., manuals, rack mount slides, etc.).
2. Open the analyzer and check for loose or damaged circuit boards, proper wiring of the input power receptacle, and tightness of tubing fittings. Note: Standard wiring configuration has the black wire connected to the brass terminal of the plug, white to copper, and green to ground. Verify that the analyzer is grounded to earth ground.
3. Assemble the analyzer as outlined in the Manufacturer's Instruction Manual, including:
 - a. Connect the vacuum pump to the exhaust of the analyzer.
 - b. Connect the dryer to the inlet of the O₃ generator, if used.
 - c. Connect the recorder signal cables to the analyzer.
 - d. Connect the sample line to the manifold.

D.2.0.3 OPERATIONAL TESTS - Perform the following checks and record the results on a mini report and on the strip chart which is retained in the Air Quality Surveillance files as a permanent record of the test performed. The data should be entered on the right hand side of the strip chart preceding the test performed. The entry should follow the following format:

Title of the test being performed

Date

Make, model number, and serial number of analyzer under test

Range on which test is being performed

Recorder trace color identification

Recorder Identification Number

Clear, precise notations should be entered on the chart indicating when the tests were started and ended, pertinent information regarding sample flow, gas concentrations, voltages, interferent gases, etc., and any unusual condition observed. All tests should be run with the integrator in and the range select on 0-1 ppm. All strip charts should be cut in 24-hour sections. All tests should be run in parallel with a control analyzer.

1. Turn on the analyzer as outlined in the Manufacturer's Instruction Manual. Check for proper operation of all flow meters, integrator circuit, vacuum gauges, temperature controllers, pump, fan, and thermoelectric cooler. Note any obvious malfunction on the chart and the mini report.
2. Check the proper adjustment of the signal processing electronics as outlined in the Manufacturer's Instruction Manual. Record the readings on the chart and adjust as necessary.
3. Photomultiplier Dark Current - After the analyzer has been operating for at least two hours (or overnight) turn the meter switch to the "NO MANUAL" mode, the ppm range to .05, and the O₃ generator off. Turn the "BACKGROUND SUPPRESSION" potentiometer to the extreme counterclockwise position. The instrument reading is the unsuppressed photomultiplier dark current; a value of less than 15 ppb is typical. Record at least one hour of unsuppressed dark current trace on the strip chart recorder. Then carefully suppress the dark current to zero using the "BACKGROUND SUPPRESSION" potentiometer. Log the final Duo Dial value on the recorder chart. Record at least one hour of suppressed dark current data. At the completion of the test, return the mode selector to the automatic mode, and turn on the ozone switch.
4. Temperature and Voltage Stability:

Place the analyzer in the Thermotron environmental chamber and connect the analyzer power cord to the variable voltage power strip. Run a temperature profile voltage test using NO₂ span gas from the permeation tube source with Aadco zero air diluent. Adjust flows to obtain an NO₂ chart trace of approximately 80% of full scale. After the temperature run is completed,

transfer the voltage and temperatures from the temperature chart to the analyzer chart next to the appropriate section of the trace. The NO trace is indicative of the zero stability, the NO₂ trace is indicative of span stability, and the NO_x trace is indicative of zero and span stability combined. The effect of temperature at 15°C and 35°C should be less than $\pm 2\%$ of full scale at span and less than $\pm 1\%$ of full scale at zero. The effects of voltage variation should be less than .01 ppm at zero and span.

5. Zero and Span Stability - Using the permeation tube system or the Dasibi Gas Calibration System, establish zero and 80% full scale traces for 30 minutes. Adjust the analyzer span if necessary so that 0.80 ppm equals 80% of full scale. If the span is adjusted, recheck the zero and permeation tubes or super blend cylinder used. After 24 and 72 hours, repeat the zero and span traces for 30 minutes. The zero and span should not drift by more than $\pm 1\%$ for 24 hours ($\pm .01$ ppm) and $\pm 2\%$ for 72 hours ($\pm .02$ ppm).

6. Linearity - After zero and span points have been set in the above test, run an auto program using the Dasibi Gas Calibration System to generate a range of four test concentrations. Verify from the strip charts that stable traces are being obtained at each point. Nonlinearity (deviations from predicted concentrations) should not exceed $\pm 1\%$ of full scale. The predicted NO concentration is obtained by using the reference analyzer's chart readings to calculate dilution factors that are then multiplied by the test analyzer's initial NO chart reading. The following example illustrates the procedure.

LINEARITY TEST						
Reference <i>TECO 14B #4769</i>				Test Analyzer		
	Gross	Net	Pred	Gross	Net	Pred
Level 0%	<i>+.1</i>			<i>+.3</i>		
(1) 80%	<i>68.3</i>	<i>68.2</i>	<i>BASE</i>	<i>73.5</i>	<i>73.2</i>	<i>BASE</i>
(2) 40%	<i>34.6</i>	<i>34.5</i>	<i>34.1</i>	<i>37.2</i>	<i>36.9</i>	<i>37.0</i>
(3) 20%	<i>17.3</i>	<i>17.2</i>	<i>17.1</i>	<i>18.8</i>	<i>18.5</i>	<i>18.4</i>
(4) 10%	<i>8.1</i>	<i>8.0</i>	<i>8.5</i>	<i>9.2</i>	<i>8.9</i>	<i>8.6</i>

i.e., the predicted NO value at level (2) =

$$\frac{34.5 \text{ (Ref. Net)}}{68.2 \text{ (Ref. Net)}} \times 73.2 \text{ (Test Net)} = 37.0\%$$

The nonlinearity at this level is $36.9 - 37.0 = -0.1\%$.

7. NO₂/NO Converter Efficiency - Using the auto program data generated in step 6, calculate the converter efficiency for each of the four auto program test concentrations. Refer to the equation in Section G.4.0, Part 2. Average the four values and record the average converter efficiency in Section III H. of the Mini Report. The average converter efficiency should be greater than 98% initially (new analyzer). Otherwise, replace the converter.

D.2.0.4 FINAL REVIEW - If all tests are satisfactory, an equipment relocation notification tag should be completed, and pertinent information such as reaction chamber vacuum, ozone flow setting, zero and span settings, converter efficiency, etc., should be recorded in the acceptance test mini report. Record equipment numbers, date completed, and any other appropriate information in your progress report. The analyzer is now ready for field use.

CHEMILUMINESCENT NO-NO₂-NO_x ANALYZER

ACCEPTANCE TEST "MINI REPORT"

Date 4-23-80
By J. DUNLAP

Make & Model No. TECO 14B
ARB No. 4973

Serial No. AAM/E 6421855
Reviewed by F.L. SMITH
Date of Acceptance 5-16-80

I. PHYSICAL INSPECTIONS

- A. Checked for shipping damage
- B. Checked all electrical wiring
- C. Checked all plumbing for leaks
- D. Analyzer complete upon receipt

Passed	Failed	Final OK
✓		
✓		
✓		
✓		
✓		
	✓	✓

II. OPERATIONAL CHECKS

- A. Checked operation of valves, controls, meters, pumps, switches, indicator lamps, etc.
- B. Set electrical zero and span

III. TESTS PERFORMED (Attach Charts)

- A. 24 Hour Zero Drift
- B. 24 Hour Span Drift @ 0.699 ppm
- C. 72 Hour Zero Drift
- D. 72 Hour Span Drift @ 0.699 ppm
- E. Linearity (% FS Dev. from predicted)
 - 80% Full Scale
 - 40% Full Scale
 - 20% Full Scale
 - 10% Full Scale
- G. Temperature and voltage variation
 - Zero Shift: 35°C, 115V
 - 35°C, 125V
 - 35°C, 105V
 - 15°C, 115V
 - 15°C, 125V
 - 15°C, 105V
 - Span @ 0.672 ppm
 - 35°C, 115V
 - 35°C, 125V
 - 35°C, 105V
 - 15°C, 115V
 - 15°C, 125V
 - 15°C, 105V

% FS Dev	Range	Pass	Fail	Final OK
- 0.1	1.0	✓		
0		✓		
0		✓		
+ 0.2		✓		
0		✓		
+ 0.3		✓		
+ 0.6		✓		
0		✓		
0		✓		
0		✓		
0		✓		
0		✓		
0		✓		
+ 0.5		✓		
- 0.5		✓		
+ 1.0		✓		
- 0.2		✓		
- 0.7		✓		
+ 0.2		✓		

H. Converter Efficiency (average) 99.1 %

I. Final Analyzer Readings: Low Voltage Supply +15.271 VDC; -15.297 VDC
PMT High Voltage -1434 VDC; Flow: 0.705 SLPM @ 3.5 Flow Setting
PMT Switch: Low (Medium) High Ozone Setting 4.8

IV. SPECIAL TESTS

V. COMMENTS/MAINTENANCE PERFORMED

II B: UNABLE TO SET NO₂ Z, RESPONSE DRIFTED WHEN DRAWER WAS OPENED OR CLOSED. REPLACED IC-3 ON ELECTROMETER BOARD.

Figure D.2.0.1
Acceptance Test Mini Report

STATE OF CALIFORNIA
AIR RESOURCES BOARD

AIR MONITORING QUALITY ASSURANCE

VOLUME II

STANDARD OPERATING PROCEDURES

FOR

AIR QUALITY MONITORING

APPENDIX D.3

CALIBRATION PROCEDURE

FOR

CHEMILUMINESCENT NO-NO₂-NO_x ANALYZERS

MONITORING AND LABORATORY DIVISION

APRIL 1985

D.3.0 CALIBRATION PROCEDURE OVERVIEWS

D.3.0.1 INTRODUCTION - Currently, the Air Resources Board uses the calibration procedure for chemiluminescent NO-NO₂-NO_x analyzers outlined in Section D.3.1, based on the gas phase titration of NO with O₃, using NO as the standard. The procedure is approved by the Environmental Protection Agency for use in California. The apparatus and dynamic parameter specifications outlined below are applicable to the procedure. The information presented is identical to that presented in 40 CFR 50.1, Appendix F, July 1, 1977.

D.3.0.2 BASIC APPARATUS - Figure D.3.0.1, a schematic of a typical GPT apparatus, shows the suggested configuration of the components listed below. All connections between components in the calibration system downstream from the O₃ generator should be of glass, Teflon*, or other nonreactive material.

1. Air flow controllers. Devices capable of maintaining air flows constant to within $\pm 2\%$.
2. NO flow controller. A device capable of maintaining NO flows constant to within $\pm 2\%$. Component parts in contact with the NO should be of a nonreactive material.
3. Air flow meters. Calibrated flow meters capable of measuring and monitoring air flow rates with an accuracy of $\pm 5\%$ of the measured flow rate.
4. NO flow meter. A calibrated flow meter capable of measuring and monitoring NO flow rates with an accuracy of $\pm 5\%$ of the measured flow rate.
5. Pressure regulator for source NO cylinder. This regulator must have a nonreactive diaphragm and internal parts and a suitable delivery pressure.
6. Ozone generator. The generator must be capable of generating sufficient and stable levels of O₃ for reaction with NO to generate NO₂ concentrations in the range required. Ozone generators of the electric discharge type may produce NO and NO₂ and are not recommended.
7. Valve. A valve is used as shown in Figure D.3.0.1 to divert the NO flow when zero air is required at the manifold. The valve should be constructed of glass, Teflon, or other nonreactive material. The valve is used to divert the NO flow when zero air or ozone is required at the manifold.

* Trade Mark - DuPont Corporation

8. Reaction chamber. A chamber, constructed of glass, Teflon, or other non-reactive material for the quantitative reaction of O₃ with excess NO. The chamber should be of sufficient volume (VRC) such that the residence time (tr) meets the requirements specified in D.3.0.3. For practical reasons, tr should be less than 2 minutes.
9. Mixing chamber. A chamber constructed of glass, Teflon, or other non-reactive material is designed to provide thorough mixing of reaction products and diluent air. The residence time is not critical when the dynamic parameter specification given in D.3.0.3 is met.
10. Output manifold. The output manifold should be constructed of glass, Teflon, or other non-reactive material and should be of sufficient diameter to insure an insignificant pressure drop at the analyzer connection. The system must have a vent designed to insure atmospheric pressure at the manifold and to prevent ambient air from entering the manifold.
11. Inline particulate filter. Install a 7 micron nominal inline particulate filter between the NO₂ scrubber and the NO flow controller.

D.3.0.3

DYNAMIC PARAMETER SPECIFICATION

1. The O₃ generator air flow (FO) and NO flow rate (FNO) (see Figure D.3.0.1) must be adjusted such that the following relationship holds:

$$PR = [NO]RC \times tr > 2.75 \text{ ppm min}$$

$$[NO]RC = [NO]S \frac{FNO}{FO + FNO}$$

$$tr = \frac{VRC}{FO + FNO}$$

Where: PR = dynamic parameter specification, determined empirically, to insure complete reaction of the available O₃, ppm-min.

[NO]RC = NO concentration in the reaction chamber, ppm.

tr = residence time of the reactant gases in the reaction chamber, min.

[NO]S = concentration of the undiluted NO source, ppm.

FNO = NO flow rate, sccm/min.

FO = O₃ generator air flow rate, sccm/min.

VRC = volume of the reaction chamber, sccm.

2. The flow conditions to be used in the GPT system are determined by the following procedure:

- a. Determine FT, the total flow required at the output manifold.
 (FT = analyzer demand plus 10 to 50% excess.)
- b. Establish [NO]OUT as the highest NO concentration (ppm) which will be required at the output manifold. [NO]OUT should be approximately equivalent to 90% of the upper range limit (URL) of the NO concentration range to be covered.
- c. Determine FNO as:

$$FNO = \frac{[NO]OUT \times FT}{[NO]S}$$

- d. Select a convenient or available reaction chamber volume. Initially, a trial VRC may be selected to be in the range approximately 200 to 500 sccm.
- e. Compute FO as

$$FO = \frac{[NO]S \times FNO \times VRC}{2.75} - FNO$$

- f. Compute tr as

$$tr = \frac{VRC}{FO + FNO}$$

Verify that $tr < 2$ min. If not, select a reaction chamber with a small VRC.

- g. Compute the diluent air flow rate as

$$FD = FT - FO - FNO$$

Where: FD = diluent air flow rate, sccm/min.

- h. If FO turns out to be impractical for the desired system, select a reaction chamber having a different VRC and recompute FO and FD.

NOTE: A dynamic parameter lower than 2.75 ppm-min may be used if it can be determined empirically that quantitative reaction of O₃ with NO occurs. A procedure for making this determination as well as a more detailed discussion of the above requirements and other related considerations is given in Reference 1.

D.3.0.4

REFERENCES

1. Ellis, E.C., "Technical Assistance Document for the Chemiluminescence Measurement of Nitrogen Dioxide," EPA-E600/4-75-003.
2. Quality Assurance Handbook for Air Pollution Measurement Systems; Volume II, "Ambient Air Specific Methods," EPA-600/4-77-027a, May 1977, (Section 2.3.2 - July 1, 1979).
3. McElroy, F.F., Technical Assistance Document: "Transfer Standards for Calibration of Air Monitoring Analyzers for Ozone," EPA-600-4-79-056, September, 1979.

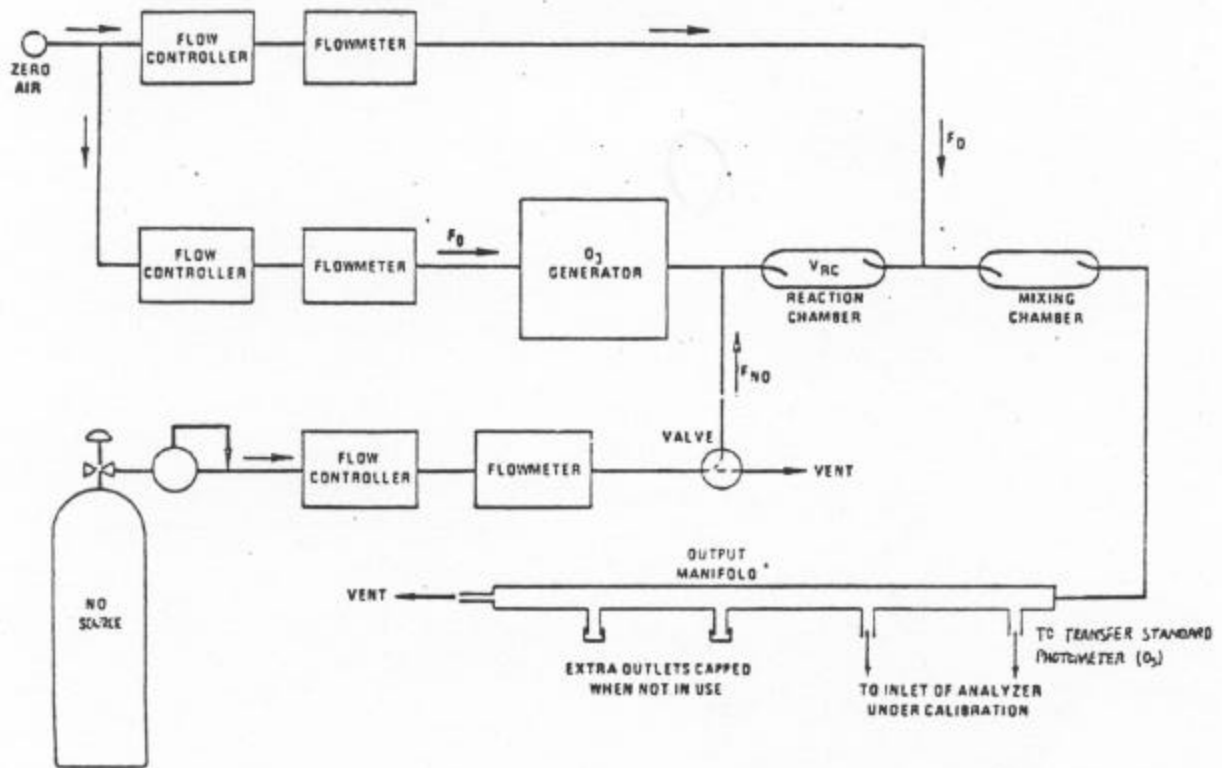
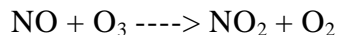


Figure D.3.0.1
 Diagram of Typical GPT Calibration System

D.3.1 GAS PHASE TITRATION CALIBRATION

D.3.1.1 PRINCIPLE - This calibration technique is based on the rapid gas phase reaction of NO and O₃, which produces stoichiometric quantities of NO₂ as shown by the following equation:



Since the NO concentration is known for this reaction, the resultant concentration of NO₂ can be determined. Ozone is added to excess NO in a dynamic calibration system and the NO channel of the chemiluminescent analyzer detects the changes in NO concentration. After the addition of ozone, the observed decrease in NO concentration on the calibrated NO channel is equivalent to the concentration of NO₂ produced. The amount of NO₂ generated may be varied by adding varying amounts of O₃ from a stable O₃ generator.

D.3.1.2 APPARATUS

1. Chemiluminescent NO-NO₂-NO_x analyzer with strip chart recorder(s), or other recording device.
2. Stable ozone generator.
3. One-quarter or one-eighth inch Teflon* tubing for airflow connections.
4. NO concentration standard - Compressed gas cylinder containing 50 to 100 ppm NO in oxygen free N₂ with less than 1 ppm NO₂. The cylinder must be traceable to a National Bureau of Standards NO in N₂ Standard Reference Material.
5. Zero Air - Air, free of contaminants which will cause a detectable response on the NO-NO₂-NO_x analyzer or which might react with either NO, O₃, or NO₂ in the gas phase titration. A procedure for generating zero air is given in Reference 1 (see Section D.3.0.4).
6. Gas phase titration (GPT) dynamic calibration apparatus (see Section D.3.0).
7. Calibration Data Form (Figure D.3.1.1).

* Trade Mark - DuPont Corporation

D.3.1.3 "AS IS" CALIBRATION - Other than routine daily checks, analyzer repairs or adjustments should not be made prior to the "As Is" calibrations.

1. Assemble a dynamic calibration system such as the one shown in Figure D.3.0.1.
2. Record analyzer parameters and site conditions on the attached calibration data form.
3. Insure that all flow meters are calibrated under the conditions of use against a reliable standard such as a soap bubble meter, mass flow meter transfer standard or wet test meter. All volumetric flowrates should be corrected to 25°C and 760 mmHg.
4. Precautions must be taken to remove O₂ and other contaminants from the NO pressure regulator and delivery system prior to the start of calibration to avoid any conversion of the source NO to NO₂. Failure to do so may cause significant errors in calibration. The problem may be minimized by:
 - a. Carefully evacuating the regulator, when possible, after the regulator has been connected to the cylinder and before opening the cylinder valve,
 - b. thoroughly flushing the regulator and delivery system with NO after opening the cylinder valve; and
 - c. not removing the regulator from the cylinder between calibrations (unless transport is involved).
5. Select the correct NO, NO₂ and NO_x operating ranges. Perform the appropriate analyzer electronic checks.
6. Determine the GPT flow conditions required to meet the dynamic parameter specification indicated in Section D.3.0.3.

NOTE: Reference to analyzer responses in the following procedures refer to the strip chart recorder, or other primary data recording system response.

7. Adjust the diluent air and O₃ generator air flows to obtain the flows determined in Step 6 above. The total air flow must exceed the total demand of the analyzer(s) connected to the output manifold to insure that no ambient air is pulled into the manifold vent. Allow the analyzer to sample zero air until stable NO, NO₂, and NO_x responses are obtained. After the responses have stabilized, adjust the analyzer zero controls. Record the stable "As Is" zero air responses as ZNO, ZNO₂, and ZNO_x. For most analyzers, the response to zero air is about the same when the analyzer ozonator is turned off (dark current only). This test serves as a double check on the zero response. None of the responses should be more than $\pm 1\%$ of full scale off the baseline. If any of the responses are more than $\pm 1\%$ of full scale off the baseline, check all connections for leaks, etc.
8. Adjust FNO to generate an NO concentration near 90% of the NO upper range limit (URL). After the NO and NO_x responses stabilize, record the analyzer's NO and NO_x responses as [NO]O₃ off and [NO_x]O₃ off, respectively. Adjust the O₃ generator to generate sufficient O₃ to produce a decrease in the NO concentration equivalent to approximately 80% of the NO₂ URL. The decrease must not exceed 90% of the NO concentration. After the analyzer responses have stabilized, record the NO, NO₂ and NO_x responses as [NO]O₃ on, [NO₂]O₃ on and [NO_x]O₃ on. Turn off the O₃ generator and let the responses restabilize.
9. Repeat Step 8 for at least two and preferably four additional ozone concentrations (e.g., 60%, 40%, 20%, and 10% of the NO₂ URL).
10. Adjust the NO flow from the standard NO cylinder to generate an NO concentration of approximately 80% of the NO URL. Calculate the exact NO and NO_x concentrations:

$$[\text{NO}]_{\text{OUT}} = \frac{F_{\text{NO}} \times [\text{NO}]_{\text{S}}}{F_{\text{NO}} + F_{\text{O}} + F_{\text{D}}} \quad [\text{NO}_x]_{\text{OUT}} = \frac{F_{\text{NO}_x} \times [\text{NO}_x]_{\text{S}}}{F_{\text{NO}_x} + F_{\text{O}} + F_{\text{D}}}$$

Where: [NO]OUT, [Nox]OUT = diluted concentrations at the output manifold, in ppm

After the NO and NO_x responses stabilize, record the NO and NO_x concentrations and analyzer's NO and NO_x responses as [NO]O₃ off and [NO_x]O₃ off.

11. Generate at least two and preferably four additional concentrations evenly spaced across the scale (for instance 60%, 40%, 20% and 10% of URL) by decreasing FNO or increasing FD. For each concentration generated, calculate the exact NO and NO_x concentrations using the equations in Step 10 above. Record the analyzer's NO and NO_x responses for each concentration on page 2 of the Calibration Data Sheet.

12. Perform the following tasks:

- a. Plot the NO calibration curve:

[NO]O₃ off (from Step 11) versus [NO]OUT

Calculate the slope and intercept of the line using linear regression analysis.

- b. Plot the NO_x calibration curve:

[NO_x]O₃ off versus [NO_x]OUT

Calculate the slope and intercept of the line using linear regression analysis.

- c. For each point, calculate the converter efficiency:

$$\text{C.E.} = \frac{\Delta \text{NO} - \Delta \text{NO}_x}{\Delta \text{NO}} \times 100$$

Calculate the average converter efficiency.

- d. Calculate the percent difference from true for NO and NO_x:

$$\% \text{ D, NO,} = \frac{\sum [\text{NO}] \text{O}_3 \text{ off} - 1}{\sum (\text{NO}) \text{O}_3 \text{ OUT}} \times 100$$

$$\% \text{ D, NO}_x, = \frac{\sum [\text{NO}] \text{O}_3 \text{ off} - 1}{\sum [\text{NO}] \text{O}_3 \text{ OUT}} \times 100$$

- e. Calculate the percent change from the previous calibration for NO and NO_x:

$$\% \text{ Change} = \frac{[S_{\text{NEW}} - S_{\text{OLD}}]}{S_{\text{OLD}}} \times 100$$

Where S = slope of the linear regression line for NO and NO_x, respectively.

D.3.1.4 "FINAL" CALIBRATION - If the percent difference reported for NO is greater than 10%, or if the converter efficiency is less than 96%, determine the cause and repair the analyzer. Then repeat Steps 1 through 7 of Section D.3.1.3 and adjust the analyzer as follows:

1. Adjustment of the NO and NO_x Span Controls. Adjust the NO flow from the standard NO cylinder to generate an NO concentration of approximately 80% of the NO URL. Calculate the exact NO and NO_x concentrations using equations in Section D.3.1.3.
 - a. Sample the NO concentration until the NO and NO_x responses stabilize. Adjust the NO span control to obtain a recorder response in agreement with the calculated [NO]OUT. If substantial adjustment of the span control is necessary, recheck the zero and span.
 - b. If the analyzer has two or three span controls, adjust the NO_x span control to obtain a recorder response of NO_x in agreement with [NO_x]OUT.
 - c. If substantial adjustment of the span controls is necessary, recheck the zero and span adjustments by repeating Step 7 of Section D.3.1.3 and Steps a and b above.
 - d. Record the new zero and span settings.
2. Adjustment of the NO₂ Span Control.
 - a. Adjust the NO flow from the standard NO cylinder to generate an NO concentration of approximately 90% of the NO URL. Sample this NO

concentration until the NO and NO_x responses stabilize. Record the analyzer responses as [NO]O₃ off and [NO_x]O₃ off.

- b. Adjust the O₃ generator to generate sufficient O₃ to produce a decrease in the NO concentration equivalent to approximately 80% of the NO₂ URL. The decrease must not exceed 90% of the NO concentration. After the analyzer responses stabilize, record the resultant NO, NO_x, and NO₂ responses as [NO]O₃ on, [NO₂]O₃ on, and [NO_x]O₃ on. The NO₂ response should agree with the change in NO response to within $\pm 2\%$.

- c. Adjust the NO₂ span control to obtain a recorder response equivalent to:

$$[\text{NO}_2]\text{OUT} = [\text{NO}]\text{O}_3 \text{ off} - [\text{NO}]\text{O}_3 \text{ on}$$

NOTE: If the analyzer has only one or two span controls, the span adjustments are made on the NO channel or on the NO and NO_x channels, and no further adjustment is made here for NO₂. If substantial adjustment of the NO₂ span control is necessary, recheck the zero and span responses.

- d. Record the final zero and span control settings.

3. Once the adjustments are complete, perform a full multipoint calibration beginning with Step 7 of Section D.3.1.3.

Figure D.3.1.1
NO-NO₂-NO_x Chemiluminescent Analyzer Calibration Datasheet

PRIMARY DATA ACQUISITION SYSTEM (DAS) IDENTIFICATION

NITRIC OXIDE CALIBRATION

[illegible]
$$\text{NO: } \left(\frac{\sum \text{NO Net DAS}}{\sum [\text{NO}]_{\text{OUT}}} - 1 \right) \times 100\% = \underline{\hspace{2cm}}\%$$
$$\text{NOx: } \left(\frac{\sum \text{NOx Net DAS}}{\sum [\text{NOx}]_{\text{OUT}}} - 1 \right) \times 100\% = \underline{\hspace{2cm}}\%$$

Linear Regression: Analyzer Response (ppm), NO, = $\left(\frac{\quad}{\text{Slope}} \right) ([\text{NO}]_{\text{OUT}}) + \left(\frac{\quad}{\text{Intercept}} \right) \text{ ppm}$

$$\text{Analyzer Response (ppm), NO}_x = \left(\frac{\quad}{\text{Slope}} \right) ([\text{NO}_x]_{\text{OUT}}) + \left(\frac{\quad}{\text{Intercept}} \right)$$

As Is Change From Previous Calibration Dated _____ Slope _____ :

NO: $\left(\frac{\text{As Is Slope} - \text{Old Slope}}{\text{Old Slope}} \right) \times 100\% = (\quad) \times 100\% = \quad \%$

$$NOx: \left(\frac{\text{As Is Slope} - \text{Old Slope}}{\text{Old Slope}} \right) \times 100\% = \left(\frac{\quad}{\quad} \right) \times 100\% = \quad\%$$

Comments: _____

Calibrated By _____ Checked By _____

Figure D.3.1.1 (cont'd)

NO-NO₂-NO_x Chemiluminescent Analyzer Calibration Datasheet